Integration of PATH Chapter 6 Interim Survival Goals With Chapter 5 Passage Mortality Estimation Procedures (7/23/97 Draft)

Chris Toole
National Marine Fisheries Service

Abstract

This report is in three parts. The first section examines whether the implicit "delayed" mortality component of the Chapter 6 interim passage survival goal can be stated explicitly using information derived from the Chapter 5 MLE analysis. The result is dependent upon one's assumptions regarding "delayed" hydro-related mortality below Bonneville Dam. Under the hypothesis that terms in the MLE analysis include "delayed" hydro-related mortality, the "direct" passage survival goal of 42-68% is coupled with no more than 19-50% additional hydro-related "delayed" mortality below Bonneville Dam. Under the hypothesis that terms in the MLE analysis include "differential" post-Bonneville mortality of upriver and downriver stocks, unrelated to passage through the hydro system, hydro-related "delayed" mortality is either non-existent or unknown.

The second section of the report examines whether the Chapter 6 ad hoc method of adjusting the 42-68% interim passage survival goal to 50-70% can be improved upon by considering the Chapter 5 "year effect" term in the MLE analysis and changes in harvest rate and adult passage survival since the 1960s. Results of this section indicate that reductions in adult harvest and passage mortality since the 1960s compensate for adjustment of above-average "year effects" in the 1960s to average and certain below-average future conditions. Therefore, the original 42-68% passage survival goal appears to be adequate without further adjustment. However, if a future management goal specifies a return to 1960s harvest rates, the interim passage survival goal under average environmental conditions would have to increase to 49-79%. These conclusions are independent of post-Bonneville "delayed" or "differential" mortality hypotheses.

The third section suggests a method for representing smolt-to-adult return rate (SAR) in prospective modeling analyses. An important component of Chapter 6 was an interim SAR goal, against which empirical estimates of SAR for transported and non-transported fish from historical and ongoing studies can be compared. However, the Chapter 5 MLE and the related Bayesian prospective model currently do not estimate SAR, so (1) correspondence of the Chapter 6 interim goal with survival and recovery performance measures cannot be evaluated and (2) if the interim SAR goal is validated, we have no method of projecting proposed management actions in terms of SAR to compare with empirical results. The method proposed in the third section defines a relation between Raymond's (1988) BY 1962-71 and 1973-82 SAR estimates and corresponding MLE estimates of "year effects" and "passage/differential mortality." This approach is not

dependent upon an assumption that MLE terms contain either "delayed" hydro-related mortality or "differential" upstream/downstream mortality. Using this relationship, the MLE model output provides reasonable estimates of SAR during most years in the 1962-82 time series and predicts SARs for the 1983-89 brood years. However, these estimates should be viewed with caution because the relationship among variables was not statistically significant if 5-year running averages were used (to account for ageing imprecision in Raymond's SAR estimates), if the 1972 brood year was included (no explanation for this outlier is obvious), or if the correlation coefficient was adjusted for intra-series autocorrelations. It should be possible to test the SAR predicted by this method for the 1990 and future brood years against empirical estimates of corresponding years' SAR using independent information and methods in PATH Chapter 9. If results are reasonable, this could be a simple method of estimating SAR explicitly in the prospective analysis.

Background

Chapter 6 of the September 1996 PATH Retrospective Analysis Report (Marmorek et al. 1996a) identified two interim survival goals with which to evaluate Hydro management actions. These survival goals correspond to empirical survival estimates available historically and from ongoing studies.

One was a **50-70% passage survival goal** from the head of Lower Granite Reservoir to below Bonneville Dam. This goal was derived from estimates of passage survival over the same reach during a four-dam configuration in "the 1960s" (42-68%), prior to the recent period of decline. The 42-68% estimate was adjusted upward by an ad hoc procedure to reflect uncertainty about estimation methods and the possibility that good ocean survival in "the 1960s" may have masked inadequate passage survival. Chapter 6 did not explicitly specify "delayed" passage mortality (i.e., differential mortality below Bonneville Dam experienced by fish that passed through the hydro system [or some critical section of it], compared to fish that did not pass through the hydro system [or through that critical section]) in the interim passage survival goal, but implicit was an assumption that delayed mortality, if any, would be no higher than that which occurred during "the 1960s" (Marmorek et al. 1996b).

The second was a **2-6% smolt-to-adult return rate (SAR) goal**. We did not explicitly define "smolt-to-adult" and cited various studies which defined this term differently. Historically, it has referred to survival from the time juveniles pass the uppermost dam to the time adults return to Ice Harbor Dam, regardless of how many additional dams were in place upstream. Most authors of Chapter 6 of Marmorek et al. (1996a) assumed that under the current hydro system configuration, the interim SAR goal would be applied to survival from the time fish passed Lower Granite Dam as juveniles until the time they returned as adults to the same site. However, the interim SAR goal was largely based on historical returns to Ice Harbor, so the exact definition of the Chapter 6 SAR remains problematic.

Three methods were used to estimate the interim SAR goal. The primary method assumed that SARs observed during periods in which cohort replacement rates for most spring/summer chinook index stocks were $\geq$1.0 are necessary for survival and recovery. Cohorts that migrated in 1964, 1967, 1970, and 1982-85 met this criterion. (Corresponding brood years are two years earlier). Raymond's (1988) 1962-1982 BY estimates of [SAR·(1-Harvest)$^{-1}$] were converted to SARs from the uppermost dam to adults at Ice Harbor. A range of approximately 2-4% was experienced by the 1962-1968 brood years. Estimated SARs were lower (approximately 1.4-3.0%) for the 1980-82 brood years. (Raymond [1988] did not estimate SAR for BY 1983). A second method back-calculated Lower Granite-to-Lower Granite SARs needed for replacement, given estimates of adult-to-smolt survival and prespawning survival for 1962-82 and 1990-93 brood years, which were estimated in Chapter 9 of Marmorek et al. (1996a). The resulting SAR estimates ranged from 0.5-4.6%. A third method assumed that it is necessary to achieve the SAR of brood year 1975-1988 Warm Springs spring chinook (1.0-5.5%; mean 3.1%). This SAR was based on estimates of juveniles passing a smolt trap near the mouth of the Warm Springs River and estimates of adults returning to the mouth of the Deschutes River. Although the second and third methods include values less than 2% within their ranges, we did not feel that it was appropriate to incorporate them into the interim goal because they were either associated with low population sizes (i.e., density dependence in the adult-to-smolt stage may have allowed for replacement at low SAR levels) or with years in which above-average ocean survival, which is a component of the SAR, was believed to occur. Selection of the 2% minimum was ad hoc.

Chapter 6 stated that these interim goals must be evaluated in the context of the prospective analysis. The prospective analysis will rely largely on a Bayesian framework that builds upon the maximum likelihood estimation (MLE) model structure presented in Chapter 5 of the PATH retrospective analysis (Marmorek et al. 1996a). One task identified at the Wenatchee PATH workshop was to develop methods for integrating the Chapter 5 and Chapter 6 approaches. This report is intended mainly as a point of departure for further discussions.

The three specific goals of this report, which correspond to the three sections below, are:

1. Explicitly estimate the implicit "delayed" mortality component of the Chapter 6 interim passage survival goal, using information derived from the Chapter 5 MLE analysis.

> Currently, the interim goal includes delayed mortality "no greater than that which occurred during the 1960s." This section attempts to estimate 1960s delayed mortality, given two general hypotheses about the representation of delayed mortality in the MLE model.

2. Improve upon the Chapter 6 ad hoc method of adjusting the 42-68% interim passage survival goal to 50-70% by considering the Chapter 5 "year effect" term in the MLE analysis and changes in harvest rate and adult passage survival since the 1960s.

> The "year effect" MLE term provides a quantitative means of relating environmental conditions to survival. If we know that survival was x% higher than average in the 1960s

due to favorable climatic conditions, then we must adjust mean 1960s passage survival or some other life-stage survival (e.g., harvest, adult passage) upwards under average environmental conditions to achieve the mean 1960s smolt-to-adult survival.

3. Propose a method for representing smolt-to-adult return rate (SAR) in prospective modeling analyses.

The interim SAR goal was an important component of Chapter 6 and some of the most important empirical information that we will be receiving during the next two years will be SAR estimates for transported and non-transported fish. Currently, we have no means of evaluating the validity of the interim SAR goal relative to survival and recovery criteria and we have no way of projecting SAR through the prospective analysis. This section describes a correlation between historical SAR estimates and MLE parameters and suggests that SAR can be projected in prospective analyses if the historical relationship persists. This is perhaps an overly simple approach, but is proposed to at least generate additional discussion of this issue. My hope is that PATH prospective analyses (which to date have generated parameter estimates with no empirical counterparts) may become more directly comparable with new results from ongoing experiments if SAR is incorporated into the analysis.

Section 1. Explicitly estimate the implicit "delayed" mortality component of the Chapter 6 interim passage survival goal, using information derived from the Chapter 5 MLE analysis.

The MLE model of Chapter 5 expressed the survival that could be associated with dam passage prior to the 1970 brood year as:

(1) $$e^{-X \cdot n}$$

where X is a constant mortality per dam and n is the number of dams in place. X is estimated by treating "in-river passage mortality" ($m_{t,i}$ in Equation 4c of Chapter 5) as a process proportional to the number of dams passed by salmon during their passage to the ocean. X includes only incremental mortality associated with dams and does not include background "natural" mortality, which would occur during passage through the river reach in the absence of dams. There are two alternative hypotheses to explain the extent, if any, to which this term reflects "delayed" mortality caused by passage past Snake River dams and reservoirs (Marmorek et al. 1996b, section 3a.2; Williams et al. 1997).

Approach To Estimating 1960s Delayed Mortality Assuming Hypothesis 1 The first hypothesis, expressed in Chapter 5 of Marmorek et al. (1996a), considers the term $e^{-X \cdot n}$ to include passage-related mortality expressed both within the hydro system ("direct") and "delayed" hydro-related mortality, as inferred from an analysis including upstream and downstream stocks passing through various numbers of dams and reservoirs. Deriso (1997), which updates the analysis in Chapter 5, estimated the median value of X over projects and years as 0.254 (rounded to 0.25 in subsequent calculations) for the best models. The number of dams passed by Snake River spring chinook ranged from 3-6 during the "1960s", which results in "direct+delayed" passage survival estimates ranging from 0.22-0.47 (Table 1).

Table 1. MLE estimates of passage survival based on Chapter 5 of Marmorek et al. (1996a) and Deriso (1997). Note that these estimates do not account for background "natural" mortality.

Brood Year	Migration Year	# Projects	$e^{-X \cdot n}$
58	60	3	0.472
59-65	61-67	4	0.367
66	68	5	0.287
67	69	6	0.223

Implicit in the Chapter 6 interim passage survival goal is an assumption that "delayed" mortality would be no higher than that which occurred during "the 1960s." By combining the Chapter 6 estimate of "direct" hydro survival under a 4-dam condition in the 1960s (0.42-0.68) with the MLE estimate of "direct+delayed" hydro survival under the same conditions (0.37), "delayed" mortality associated with a 1960s 4-dam configuration can be estimated. Because the "direct" hydro survival estimates includes both dam-induced mortality plus a background level of "natural" mortality, while the MLE estimate does not, an adjustment to one of the estimates is necessary. I suggest multiplying the MLE passage survival estimate by the Chapter 6 estimate of pre-dam "natural" survival (0.86-0.92), because the alternative of adjusting the "direct" mortality term would yield a term that could never be estimated directly in the field. Equations (2) and (3) describe the approach.

$$(2)\qquad \begin{gathered}(1\text{-"Direct" Passage M}) \bullet (1\text{-"Delayed" Passage M}) = \\ (\text{MLE Total Passage Survival}) \bullet (1\text{- "Natural" M})\end{gathered}$$

or, alternatively,

$$(3)\qquad e^{\ln[1\text{-"Delayed" M}]} = e^{-[X \bullet n]+\ln[1\text{-"Natural"M}]-\ln[1\text{-"Direct" Passage M}]}$$

This approach, assuming that Hypothesis 1 is correct, indicates that approximately 19-53% of spring/summer chinook smolts passing Bonneville Dam died subsequently as a result of their passage through the 4-dam hydro system existing in the 1960s (Table 2). This estimate can be used to explicitly define the maximum "delayed" mortality associated with the interim passage survival goal.

Table 2. Estimates of "delayed" mortality associated with 1960s passage survival, given Hypothesis 1, a range of "direct," "natural," and "total" survival estimates as described in the text, and Equation (3).

"Direct" S	"Natural" S	X	n	$e^{\ln[1-\text{"Delayed" M}]}$	"Delayed" M
0.42	0.86	0.25	4	0.75	0.25
0.42	0.92	0.25	4	0.81	0.19
0.68	0.86	0.25	4	0.47	0.53
0.68	0.92	0.25	4	0.50	0.50

Approach To Estimating 1960s Delayed Mortality Assuming Hypothesis 2 Under this hypothesis (Marmorek et al. 1996b, section 3.a.2; Williams et al. 1997), the expression $e^{-X \cdot n}$ in the MLE analysis represents hydro effects and "differential" non-hydro mortality among upstream and downstream stocks. Differences between Chapter 6 estimates of "direct" mortality during the 1960s and Chapter 5 MLE estimates of "total" passage mortality do not necessarily represent "delayed" hydro mortality, but may be caused by systematic differences in density-independent survival, such as ocean survival, of upstream and downstream stocks (Williams et al. 1997).

Under Hypothesis 2, it is impossible to assign an explicit estimate of hydro-related delayed mortality to the interim passage survival goal proposed in Chapter 6 using methodology of Chapter 5. In fact, Hypothesis 2 proposes that there is no hydro-related delayed mortality below Bonneville Dam caused by juvenile passage through or transport around the hydro system (Williams et al. 1997).

Section 2. Improve upon the Chapter 6 ad hoc method of adjusting the 42-68% interim passage survival goal to 50-70% by considering the Chapter 5 "year effect" term in the MLE analysis and changes in harvest rate and adult passage survival since the 1960s.

In Chapter 6 of Marmorek et al. (1996a), we used an ad hoc procedure to raise the 42-68% estimate of 1960s 4-dam in-river "direct" passage survival to 50-70%. The primary reason for making this adjustment was our understanding that climatic conditions in the 1960s were favorable to ocean survival of Snake River salmon, which could mean that 42-68% passage survival would be insufficient for attaining 1960s smolt-to-adult return rates (SAR) under average climatic conditions. By incorporating the "year effects" parameter (δ) estimated in the MLE procedure described in Chapter 5 of Marmorek et al. (1996a), an alternative to the ad hoc adjustment procedure in Chapter 6 is possible. The δ parameter represents effects common to all stocks included in the Chapter 5 MLE analysis: "this would include major ocean mortality changes that affect the survival of chinook salmon during the first two years of ocean life, as well as regional changes in terrestrial climate that affect all stocks." Because the δ parameter represents common effects among upstream and downstream stocks, rather than “differential” or “delayed” effects, this approach is consistent with both Hypothesis 1 and Hypothesis 2. However, whether the incremental change is applied solely to “direct” passage survival or to both “direct” passage survival and (1-“delayed” passage mortality) is dependent upon the hypothesis.

The "year effect" term scales annual estimates of survival to the mouth of the Columbia River in the MLE analysis as e^{δ} (Equations 4b, 4c, 4e of Chapter 5). During an average year, δ=0; during above-average survival years, δ>0; and during below-average survival years, δ<0. The 1959-1965 brood years, which migrated as juveniles through a four-dam configuration, were associated with δ ranging from -0.315 to +0.529, with a mean of +0.23 (Deriso 1997). This means that, on average, the 1959-1965 brood years experienced survival 1.26 times higher than expected ($e^{0.23} \div e^{0} = 1.26$), due to favorable conditions affecting all stocks. To achieve the same SAR under average conditions, at least one of the survival terms would have to be 1.26 times higher than originally estimated. Opportunities for increasing smolt-to-adult survival could include reducing harvest, adult hydro passage mortality, juvenile passage mortality, or some combination of these factors.

Estimation Assuming Current Harvest Rate It appears that reductions in harvest and improvements in adult passage survival since the 1960s have more than compensated for these environmental effects. Harvest on the 1959-65 brood years occurred mainly in 1963-1970. Spring chinook harvest ranged from 0.35-0.63 and averaged 0.47 (Beamesderfer et al. 1977). An average 1.26 increase in survival derived entirely from harvest reduction would require an average harvest rate of no more than 0.33 (estimated as 1-[(1-0.47)•1.26]). The harvest rate during the past 10 years (1986-1995) has ranged from 0.05-0.135 and averaged 0.09, which is considerably below the maximum level consistent with 1960s survival. The adult conversion rate, which is an approximation of adult passage survival (see Section 3 for discussion), has also improved slightly since the 1960s, in spite of the presence of more dams. Conversion rates to the uppermost dam in 1963-1970 ranged from 0.34-0.81 and averaged 0.61, while conversion rates between 1986-1995 ranged from 0.48-0.92 and averaged 0.66.

The combination of adult harvest reduction and improved conversion has resulted in average adult survival that is 1.86 times higher than the average adult survival that occurred during the 1960s with a four-dam configuration (estimated as ([1-0.09]•0.66)÷([1-0.47]•0.61)). This suggests that, as long as harvest and conversion rates remain at their recent levels, the 1960s direct four-dam juvenile survival rate of 0.42-0.68 should be more than adequate as a target to attain adult return rate comparable to those experienced by the 1959-1965 brood years, under average environmental conditions. Further, if these adult survival rates continue, the 0.42-0.68 juvenile survival rate should also result in equivalent return rates under below-average environmental conditions as poor as δ = -0.62 (estimated as ln[(0.53•0.61)÷(0.91•0.66)]). If Hypothesis 1 is accepted, the “delayed” mortality rates estimated above for the 1960s four-dam condition (Table 2) would also remain unchanged.

Estimation Assuming Increased Future Harvest Rate The above analysis suggests that, under current adult harvest and passage conditions, no adjustment to the 1960s juvenile passage survival estimate is necessary. However, it is possible that in the future regional priorities may necessitate adjustment of juvenile passage rates to accommodate increased harvest. Some combinations of harvest, adult passage, and juvenile passage mortality that would be consistent with the survival experienced by the 1957-1966 brood years, adjusted for average environmental conditions, are displayed in Table 3. In this table, e^{δ} in the first row (1957-1965 BY) represents the mean MLE estimate for that time period. In the second row, e^{δ} represents the ratio of average combined 1960s juvenile survival and current adult survival (0.25, 0.41) to the estimated average combined survival associated with $\delta=0$ (0.17, 0.28). In the third and fourth rows, e^{δ} is set to 1.0 to represent average environmental conditions, and the survivals are back-calculated.

Table 3. Estimates of average "direct" juvenile survival, 1-harvest rate, and adult conversion for historical and current conditions, coupled with options for meeting the survival goal under average environmental conditions. ***Bold*** values represent the suggested interim passage goal, coupled with recent harvest and adult passage survival rates. (See text for details).

Low Passage Survival Estimate

Condition	Juvenile Passage	(1-Harvest Rate)	Adult Conversion	Combined Survival	e^delta	Combined Survival at Delta=0
4-dam system, brood years 1957-1965	0.42	0.53	0.61	0.14	1.26	0.17
1960s juvenile survival and recent adult survival	***0.42***	***0.91***	***0.66***	***0.25***	***1.47***	
All improvement in juvenile passage; harvest increased	0.49	0.53	0.66	0.17	1.00	
Improvement split equally between harvest and juvenile passage	0.45	0.57	0.66	0.17	1.00	

High Passage Survival Estimate

Condition	Juvenile Passage	(1-Harvest Rate)	Adult Conversion	Combined Survival	e^delta	Combined Survival at Delta=0
4-dam system, brood years 1957-1965	0.68	0.53	0.61	0.22	1.26	0.28
1960s juvenile survival and recent adult survival	***0.68***	***0.91***	***0.66***	***0.41***	***1.47***	
All improvement in juvenile passage; harvest increased	0.79	0.53	0.66	0.28	1.00	
Improvement split equally between harvest and juvenile passage	0.73	0.57	0.66	0.28	1.00	

If Hypothesis 1 is accepted and one believes that future harvest and adult conversion rates will change, the adjustment to direct passage survival in Table 3 could be allocated among both direct survival and (1-“delayed” mortality). A suggested means of allocation would be to estimate a scalar (x) to proportionally adjust the estimates of 1960s passage survival and (1 - “delayed” mortality):

(4) $x = \{[(1\text{-Harvest}_{60s})\bullet(\text{Conversion}_{60s})\bullet e^{\delta}{}_{60s}]\div[(1\text{-Harvest}_{90s})\bullet(\text{Conversion}_{90s})]\}^{0.5}$

Application of this approach to the two cases of increased harvest in Table 3 gives the results in Table 4.

Table 4. Adjustment of 1960s four-dam “direct” and “delayed” passage survival (that is, 1- “delayed” mortality) to account for average environmental conditions, given that Hypothesis 1 is accepted and that future harvest rates could change as in Table 3. The adjustment to each passage survival term is estimated using Equation 4.

	"Direct"	Adj. "Direct"	"Delayed"	Adj. "Delayed"
All improvement in juvenile passage survival, harvest increased, as in Table 3:				
Low Ch.6 Estimate	0.42	0.45	0.75-0.81	0.81-0.87
High Ch. 6 Est.	0.68	0.73	0.47-0.50	0.51-0.54
Improvement split equally between harvest and juvenile passage survival as in Table 3:				
Low Ch.6 Estimate	0.42	0.44	0.75-0.81	0.78-0.84
High Ch. 6 Est.	0.68	0.71	0.47-0.50	0.49-0.52

Section 3. Propose a method for representing smolt-to-adult return rate (SAR) in prospective modeling analyses.

Overview: As stated in the Background discussion, the purpose of this section is to suggest a method of including estimates of SAR in the PATH prospective modeling analysis. The Chapter 6 interim SAR goal (see Background) was an important component of the recommended "empirical" management decision process described in Chapter 6. In particular, it was the key empirical criterion available for evaluating the adequacy of survival of transported fish. That interim goal has not been validated in relation to survival and recovery probabilities and currently the prospective analysis output cannot be directly compared to new estimates of transported and non-transported SAR, which will be available within the next two years. This section proposes a simple approach to incorporating SAR estimates into the PATH prospective analysis. It relies on a correlation between historical SAR estimates (Raymond 1988) and MLE parameter estimates for the same period. Assuming the relationship is sufficient for predictive purposes (see discussion below) and that it will persist into the future, it may be useful for projecting SARs associated with proposed management actions. It should also be possible to use this approach to determine the range of SARs associated with various probabilities of survival and recovery to validate or modify the Chapter 6 interim SAR goal. This approach is suggested primarily to stimulate discussion and generate suggestions for alternative, better, methods of considering SAR in the prospective analysis. It appeared to me that, unless someone proposed a "straw-man" such as this for incorporating SAR into the prospective analysis, PATH might overlook this task in the face of the current work load, thereby losing the opportunity to make good use of an important source of new empirical information.

Proposed Approach: The MLE procedure estimates components of survival only to the point at which adults return to the mouth of the Columbia River. Therefore, it does not explicitly estimate historical SARs, which were estimated from the time juveniles passed the uppermost dam and returned as adults to Ice Harbor Dam (Raymond 1988), or current SARs, which can be estimated from the time juveniles pass Lower Granite Dam to their return as adults to Lower Granite Dam. The prospective Bayesian model (BSM) will extend the estimates to include the entire life cycle, but in its current form, it does not explicitly produce estimates of SAR. Estimation of this parameter is important in the context of issues identified in Chapter 6, particularly those relating to efficacy of transportation. It is also important because a key source of empirical data that will become available during the next few years will be Lower Granite-to-Lower Granite SAR estimates for wild transported and non-transported spring/summer chinook salmon.

There are a number of ways that SAR may be represented in the MLE and BSM. For example, it may be possible to estimate SAR by modifying the BSM to include estimates of adult-to-smolt survival and pre-spawning (above Lower Granite Dam) survival from available years (summarized in Chapter 9 of Marmorek et al. 1996b), and combine this information with spawner-to-spawner information and other parameters estimated in the MLE. My understanding is that this approach will take some time to implement. In the meantime, I propose a simpler approach that is available immediately. Even if it is not incorporated into the prospective model, I think that it is of value in comparing historical MLE survival estimates with corresponding independent SAR estimates (Raymond 1988).

In general, this approach assumes that one can link survival estimates generated by the MLE/BSM to empirical survival estimates of the aggregate spring/summer chinook stock for various life stages (Figure 1). This is somewhat confounded by the nature of MLE/BSM estimated parameters (*a, b*, X, μ, and δ), which each apply to much of, if not the entire, life cycle and are stock-specific for *a* and *b*. However, it appears that certain of these parameters are most closely related to discrete life history stages and therefore may be proportional to empirical estimates of aggregate stock survival during these stages. This assumption was expressed, for example, in Equation 6 of Chapter 5, in which passage model survival estimates were assumed to be proportional to MLE-estimated dam survival estimates (X). Following is a set of more detailed assumptions that apply to the proposed approach.

<u>*ASSUMPTION 1A*</u>*:* This assumption corresponds to Hypothesis 1 in Section 1 of this report. It assumes that an MLE/BSM estimate of "passage survival," represented by $e^{-(X \bullet n)+\mu}$, is composed of "direct" and "delayed" mortality resulting from passage through the hydro system, expressed both within and outside of the hydro system. No other sources of mortality, such as systematic differences in estuary and ocean survival among upstream and downstream stocks, are incorporated into this expression. In addition to the parameters defined above, an additional term μ is included for post-1969 brood years. This term represents "the net dam passage mortality from the Snake River subbasins to John Day Dam ('Y' dams in Table 5-2) expressed as an instantaneous mortality rate for brood years $t \geq 1970$. The μ term is a 'net' effect mortality estimate because it reflects the overall impacts of dam passage over the complete life cycle, including direct losses due to trauma at the point of dam passage, increased 'natural mortality' owing to longer smolt residence time in dams and reservoirs, latent mortality due to a weakened condition of smolts, and the benefits or detriments of transportation by barge of some Snake River smolts down-river to below Bonneville Dam." Although the locations and times of mortality expressed in $e^{-(X \bullet n)+\mu}$ are complex, a fundamental assumption of the proposed approach is that a significant portion of the "direct" and "delayed" passage mortality is expressed somewhere between the time juveniles pass the head of the most upstream reservoir and the time they return as adults to the mouth of the Columbia River (Figure 1).

<u>*ASSUMPTION 1B*</u>*:* This assumption corresponds to Hypothesis 2 in Section 1 of this report. Under this assumption, the MLE/BSM estimate of "passage survival," represented by $e^{-(X \bullet n)+\mu}$, is composed of "direct" mortality resulting from passage through the hydro system and additional "differential" mortality resulting from systematic differences in estuary and ocean survival among upstream and downstream stocks. It may or may not include some "delayed" passage-related mortality, expressed outside of the hydro system. Although the locations and time periods in which mortality is expressed in $e^{-(X \bullet n)+\mu}$ are complex, a fundamental assumption of the proposed approach is that a significant portion of the "direct" and "differential" mortality is expressed

somewhere between the time juveniles pass the head of the most upstream reservoir and the time they return as adults to the mouth of the Columbia River.

NOTE: For purposes of the proposed approach, it does not matter whether $e^{-(X \bullet n)+\mu}$ includes "direct" + "delayed" hydro mortality or if it represents "direct" hydro mortality + "differential" non-hydro mortality. That is, it does not matter if Hypothesis 1 or 2 is correct. The important component of both Assumptions 1A and 1B is that the mortality is expressed primarily between the time at which fish reach the head of the first reservoir as smolts and time at which they return as adults to the mouth of the Columbia River. The term $e^{-(X \bullet n)+\mu}$ is referred to as "passage/differential" survival in the remainder of this report.

ASSUMPTION 2: The MLE/BSM procedures estimate mortality, additional to that included in the "passage/differential" survival term, that is expressed between smolt passage through the upper reservoir and adult return to the mouth of the Columbia. This mortality is incorporated within the Equation 5 survival term, which is derived from Equation 4c of Chapter 5.

$$e^{a-bS+\varepsilon} \bullet e^{\delta} \qquad (5)$$

In this equation, *a* and *b* represent the Ricker parameters that describe underlying productivity (including background "natural" mortality during passage through the hydro system) and δ represents annual changes in mortality experienced by both upstream and downstream stocks ("year effects"). These terms encompass the entire life cycle, but I will refer to the (unknown) component of Equation (5) that is expressed during this life stage as "non-passage" survival in the remainder of this report.

ASSUMPTION 3: Estimates of SAR can be adjusted to correspond to the life stage encompassed by "passage/differential" survival (Assumption 1) and "non-passage" survival (Assumption 2) using Equation 6.

$$\text{SAR} \bullet (\text{1-Mortality through first pool}) \bullet (\text{1-Harvest})^{-1} \bullet (\text{Adult Conversion Rate})^{-1} = e^{-(X \bullet n)+\mu} \bullet (\text{“Non-Passage” Survival}) \qquad (6)$$

An adjustment for mortality through the first reservoir must be made because the SAR mortality begins below that, at the first dam, while the MLE/BSM estimates of "passage" and "non-passage" mortality begin at the first reservoir. Adjustments for in-river harvest and adult survival rate (i.e., mortality upstream through dams and reservoirs) are necessary to express the SAR as mortality to the mouth of the Columbia River, which matches the MLE/BSM "passage" survival estimates.

ASSUMPTION 4: Raymond (1988) made reasonable estimates of wild spring chinook aggregate stock [SAR • $(\text{1-Harvest})^{-1}$] for the 1962-1982 brood years; Beamesderfer et al.'s (1997) estimates of adult conversion rates for those years are representative of adult passage mortality rates; and a reasonable range of estimates of (1-Mortality through the first pool) for those years are available from passage models, or by applying recent empirical survival estimates to those years. Harvest refers only to in-river harvest; ocean harvest is assumed to be zero (Chapter 3 of Marmorek et al. 1996a). Using these survival estimates, the left side (upper line) of Equation 6 can be estimated for each brood year between 1962-1982. Deriso (1997) provides reasonable estimates of X, n, and μ for wild spring/summer chinook brood years 1962-1982. Incorporation of these estimates into Equation 6 would allow "non-passage" survival to be estimated as in Equation 7.

(7)

$$\text{"Non-Passage" Survival} = \text{SAR} \bullet (1\text{-First Pool M}) \bullet (1\text{-Harvest})^{-1} \bullet (\text{Conversion Rate})^{-1} \bullet [e^{-(X \bullet n)+\mu}]^{-1}$$

<u>*NOTE*</u>: There are some serious problems with Raymond's (1988) estimates of historical SAR. Insufficient detail is presented to reproduce his results, particularly as they pertain to estimation of hatchery and wild components and estimation of age (G. Matthews, NMFS, pers. comm.). One method suggested for reducing the effect of incorrect ageing of adults is use of running averages, rather than annual estimates (G. Matthews, NMFS, pers. comm.). There are also concerns regarding the degree to which dam passage conversion rates (which are counts at an upstream dam minus counts at a downstream dam, adjusted for harvest and an estimate of tributary turn-offs between the dams) represent adult passage survival. For example, adults that pass a dam and then "fall back" below it and re-ascend are counted twice. Radio-telemetry studies indicate high fallback rates at some projects under some conditions (i.e., 14% fallback rate at Bonneville Dam in 1997, resulting in an inflated estimate of dam passage from ladder counts) and generally estimate higher between-dam adult survival rates than those derived from dam conversion rates (reviewed in NMFS 1995 FCRPS biological opinion). A confounding factor is that MLE parameter estimates rely on run reconstructions that are based on dam conversion rates.

<u>*ASSUMPTION 5*</u>: A key assumption is that e^{δ} is proportional to "non-passage" survival, as described in Assumption 2, for 1962-1982 brood years. This would appear to be a reasonable assumption because Chapter 5 describes δ as including major ocean mortality changes that affect the survival of chinook salmon during the first two years of ocean life. It is likely that a significant component of "non-passage" survival occurs below Bonneville Dam in the estuary or ocean. Depending upon one's perspective, the δ-related component of that "non-passage" survival (as distinct from the stock-specific *a*'s and *b*'s) is either common to upstream and downstream stocks (Hypothesis 1) or, if different, the systematic differences have already been incorporated into the "passage" survival term (Hypothesis 2).

<u>*ASSUMPTION 6*</u>*:* If there is a relation between "non-passage" survival and δ for the 1962-1982 brood years, that same relationship will persist beyond 1982. If this assumption is accepted, we should be able to project SAR (adjusted for harvest, upstream passage mortality, and first reservoir mortality) through the BSM prospective model as a function of X, n, μ, and δ by re-arranging Equation 7 (Equation 8).

(8)

$$\text{SAR} =$$

$$(\text{"Non-Passage" Survival}) \bullet (\text{1-First Pool M})^{-1} \bullet (\text{1-Harvest}) \bullet (\text{ Conversion Rate}) \bullet e^{-(X \bullet n)+\mu}$$
$$= f(\delta) \bullet (\text{1-First Pool M})^{-1} \bullet (\text{1-Harvest}) \bullet (\text{ Conversion Rate}) \bullet e^{-(X \bullet n)+\mu}$$

By examining those combinations of X, n, μ, and δ that meet survival and recovery goals, we should be able to infer the SARs that will meet the same goals, thereby either validating or modifying the interim SAR goal described in Chapter 6.

Preliminary Assessment of Proposed Method I conducted a preliminary analysis that suggests that this may be a reasonable approach. In addition to using Raymond's (1988) reported wild spring chinook SAR•(1-Harvest)$^{-1}$, I assumed 95% survival through the first reservoir (UP-RES S), based on recent PIT-tag survival estimates and discussion in Chapter 6 of Marmorek et al. (1996). Upstream passage survival was represented by Minam River spring chinook conversion rates (SPR CONV.) using estimates from Table 3 of Deriso (1997). MLE/BSM estimates of X, μ, and δ are from Table 8 of Deriso (1997). A summary of the estimates is presented in Table 5.

Table 5. Inputs to analysis to equate SAR and MLE/BSM results. Sources are described in the text. Adjusted SAR (ADJ. SAR) is estimated as the left side (upper line) of Equation 6.

BY	SAR/(1-HARVEST)	SPR CONV.	UP-RES S	ADJ. SAR	DELTA	MU	PASSAGE S e^-[(X*n)+MU]	ADJ. SAR/PASSAGE S
1962	0.037	0.557	0.95	0.0631	0.100	0	0.362	0.174
1963	0.037	0.339	0.95	0.1037	-0.027	0	0.362	0.286
1964	0.039	0.639	0.95	0.0580	-0.315	0	0.362	0.160
1965	0.061	0.768	0.95	0.0755	0.370	0	0.362	0.208
1966	0.036	0.814	0.95	0.0420	0.152	0	0.281	0.150
1967	0.053	0.476	0.95	0.1058	0.631	0	0.218	0.486
1968	0.034	0.636	0.95	0.0508	1.261	0	0.169	0.301
1969	0.024	0.385	0.95	0.0592	0.271	0	0.169	0.350
1970	0.012	0.409	0.95	0.0279	-0.181	0.509	0.281	0.099
1971	0.004	0.739	0.95	0.0051	-0.078	1.651	0.090	0.057
1972	0.016	0.279	0.95	0.0545	-0.057	2.226	0.050	1.081
1973	0.037	0.295	0.95	0.1192	0.086	0.609	0.254	0.469
1974	0.010	0.33	0.95	0.0288	-0.244	1.746	0.081	0.354
1975	0.003	0.685	0.95	0.0042	-0.419	2.733	0.030	0.137
1976	0.010	0.361	0.95	0.0263	-0.582	1.256	0.133	0.198
1977	0.012	0.41	0.95	0.0278	-0.841	0.771	0.216	0.129
1978	0.005	0.335	0.95	0.0142	-0.479	1.479	0.106	0.133
1979	0.015	0.577	0.95	0.0247	-0.442	1.232	0.136	0.181
1980	0.020	0.424	0.95	0.0448	-0.026	0.191	0.386	0.116
1981	0.021	0.526	0.95	0.0379	-0.373	0.175	0.392	0.097
1982	0.030	0.557	0.95	0.0512	0.024	0.614	0.253	0.203

Several terms discussed in the text are linearly related (Table 6). The significance of the correlations depends upon whether one relies upon parametric or non-parametric statistics and whether or not one accounts for intra-series autocorrelations.

Table 6. Correlations among terms discussed in text for BY 1962-1982. SAR/(1-H) from Raymond (1988). Adjusted SAR (ADJ. SAR) is estimated as the left side (upper line) of Equation 6. X, n, μ, and δ from Deriso (1997). "Passage/Differential" survival is $e^{-(X\bullet n)+\mu}$ and "non-passage" survival is as described in Equation (7). Number in () indicates statistical significance (P) of correlation. Pearson r and associated P are indicated in standard print, significance of Pearson r adjusted for autocorrelations is indicated in **bold** by **-** (adjusted P>0.05) or ***** (adjusted P ≤ 0.05), and Spearman rank correlation and associated P are indicated in *italics*. The adjustment for autocorrelations was calculated by C. Paulsen, using methods described in revised version of PATH Chapter 2 (June 1997).

	Adj. SAR	Passage/Diff. S	δ	Non-Passage S
SAR/(1-H)	0.812 (0.000) **(-)** *0.903* *(0.000)*	0.624 (0.003) **(-)** *0.677* *(0.003)*	0.632 (0.002) **(-)** *0.703* *(0.002)*	0.154 (0.504) **(-)** *0.445* *(0.047)*
Adj. SAR	______	0.485 (0.023) **(-)** *0.525* *(0.019)*	0.506 (0.019) **(-)** *0.723* *(0.001)*	0.428 (0.053) **(-)** *0.643* *(0.004)*
Passage/Diff. S		______	0.144 (0.535) **(-)** *0.310* *(0.166)*	-0.333 (0.141) **(-)** *-0.235* *(0.294)*
δ			______	0.270 (0.237) **(-)** *0.487* *(0.029)*

I examined the relationship between δ and "non-passage" survival using three methods. The first method was to fit a linear regression between the variables using all available brood years (1962-1982). As indicated by Table 6 and Figure 2, this relationship is not statistically significant except when estimated with the non-parametric Spearman rank correlation. The relation was not significantly improved by a suite of non-linear functions available with Statgraphics Plus statistical software. Examination of residuals indicated that the 1972 observation has a very strong influence on the regression. The Studentized residual for this observation is 7.9; whereas, all other observations have Studentized residuals <2.0.

The second approach was therefore to consider 1972 an outlier and remove it from the regression. My untested assumption is that at least one of the following is true: (1) Raymond's (1988) estimate of the 1972 SAR was in error or, at least, biased in a different manner than estimates for the other years (may be related to ageing inaccuracies described earlier); (2) other factors such as harvest, adult conversion rates, spawning counts (R/S), or ages of either upstream or downstream stocks were estimated incorrectly that year; or (3) there was a significant change in the "usual" relationship between upstream and downstream stocks that year (for unknown reasons). Whatever the cause, removal of 1972 yields a significant regression ($P=0.022$; $r=0.51$; $r^2=0.26$; Figure 2) if one assumes that the observations are independent:

$$\text{“Non-Passage” } S = 0.22176 + 0.132366 \bullet \delta \tag{9}$$

Note that there are, in fact, significant intraseries correlations and if these are taken into account, the relationship is not statistically significant ($P>0.05$).

The third method used 5-year running averages of each variable in the regression. Using this method, the number of observations was reduced from 21 to 17, the points became more correlated, and, even if independence was assumed, the relationship was not significant ($P = 0.175$). No outliers with extreme influence on the regression could be identified, since the 1972 brood year represented only 20% of any observation. Lack of a relationship among the 5-year averages suggests that the relationship described by Equation (9) is driven by short-term annual variations and is therefore highly dependent upon accurate age estimation. As discussed earlier, ageing techniques were not adequately described in Raymond (1988) and have not been reproduced. This, coupled with lack of statistical significance if autocorrelations are accounted for, suggests that analyses based on the relationship in Equation (9) should be viewed with caution.

If one accepts that (1) there is an error in either the estimation of δ or adjusted SAR for the 1972 brood, (2) age is reasonably estimated in Raymond (1988), and (3) autocorrelations can be ignored in this exploratory analysis, then the implications of Equation (9) for prospective analyses can be examined. Substituting Equation (9) for $f(\delta)$ in Equation (8) allows estimation of adjusted SAR as:

(10) $$\text{Adjusted SAR} = (0.22176 + (0.132366 \bullet \delta)) \bullet e^{-(X \bullet n)+\mu}$$

where adjusted SAR is the left side (top line) of Equation (6). Figure 3 shows the correspondence of the adjusted SAR and the function based on MLE/BSM parameters. There is a strong correlation between the variables ($r=0.79$; $r^2 = 0.63$; $P = 0.002$) although, again, it is not statistically significant at $P \leq 0.05$ when autocorrelations are considered. The MLE/BSM function tends to under-estimate adjusted SAR by about 30% (slope = 0.698) over much of the range of observations. Correspondence by brood year for 1962-1982 is shown in Figure 4. The poorest correspondence is in years such as 1967, 1972, 1973, 1980, and 1981. Predictions for brood years 1983-1989 are also presented. These suggest that adjusted SAR was relatively high in BY 1983, but has been low ever since.

Conclusions Regarding SAR Methodology The proposed method does a fairly good job of predicting the past, but its utility in projecting the future is limited by at least four key assumptions: (1) it was reasonable to drop 1992 from the initial relationship; (2) Raymond's (1988) ageing estimates are reliable; (3) the lack of a statistically significant relationship when autocorrelations are considered is less important than the apparent good fit of this relationship to past observations; and (4) this relationship can be expected to persist into the future. Any one of these could potentially define a fatal flaw in the approach, which is why I present it as a straw-man to stimulate further discussion.

One useful consideration is the ability to test the SAR predicted by Equation 10 (which pertains only to wild fish) for BY 1990 (and very soon 1991). This is because most Snake River hatchery fish began being marked for the 1992 out-migration (1990 BY) and, using techniques described in Marmorek et al. (1996a) Chapter 9, it should be possible to estimate wild SAR for the aggregate spring/summer chinook migration. I understand that BY 1990 MLE parameter estimates are presently available and expect that BY 1991 and 1992 estimates should be available soon. Additionally, beginning with BY 1993, we will have experimental estimates of transported and non-transported SARs. Nearly all of the returns from BY 1993 will be complete by 1998.

Acknowledgments

The methods for adjusting the passage survival goal using MLE parameters were first suggested by Rick Deriso at the Wenatchee workshop and have been substantially improved from an earlier draft by his comments. Charlie Paulsen provided adjusted probabilities for SAR correlations after accounting for intra-series autocorrelations.

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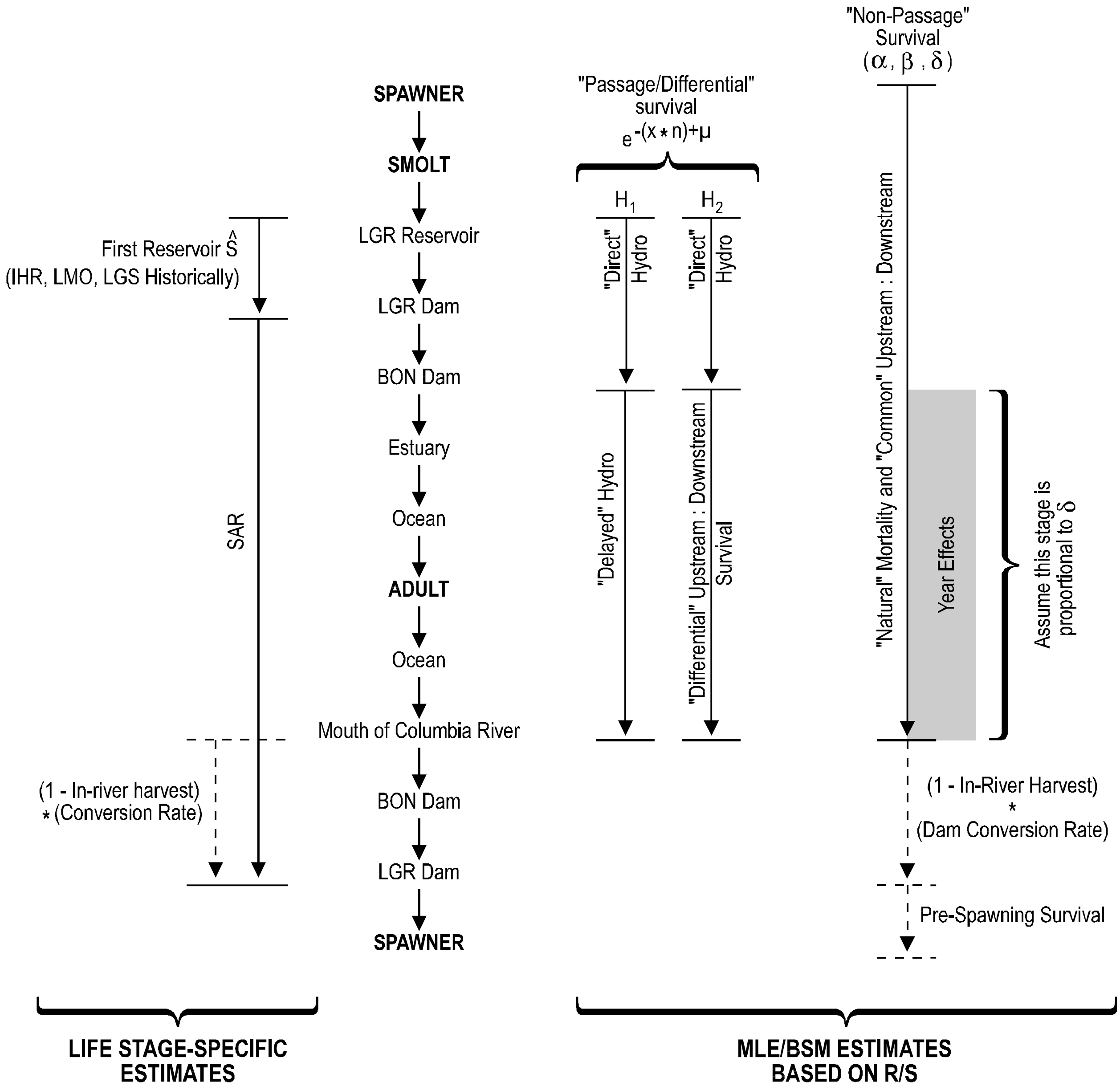

Figure 1. Comparison of survival estimates from MLE/BSM and other sources.

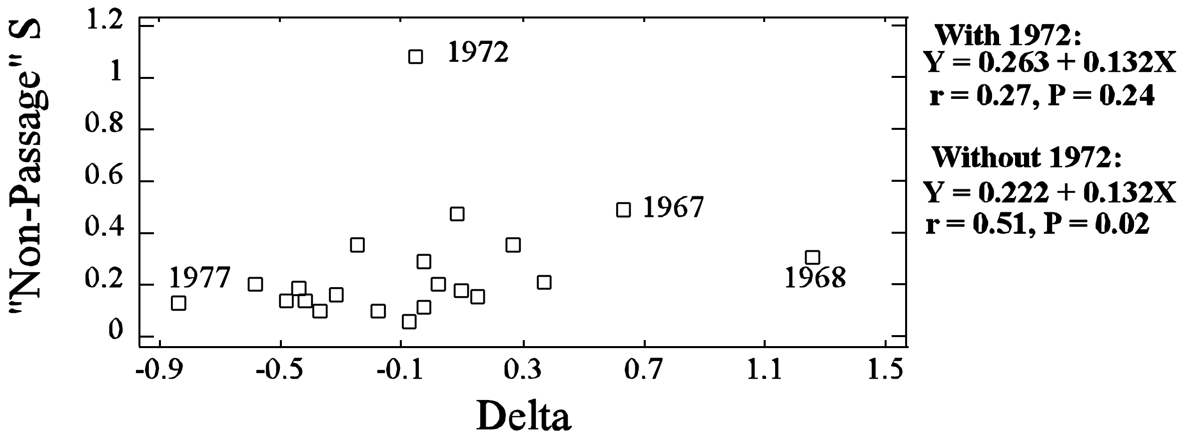

Figure 2. Correspondence of delta and “non-passage survival

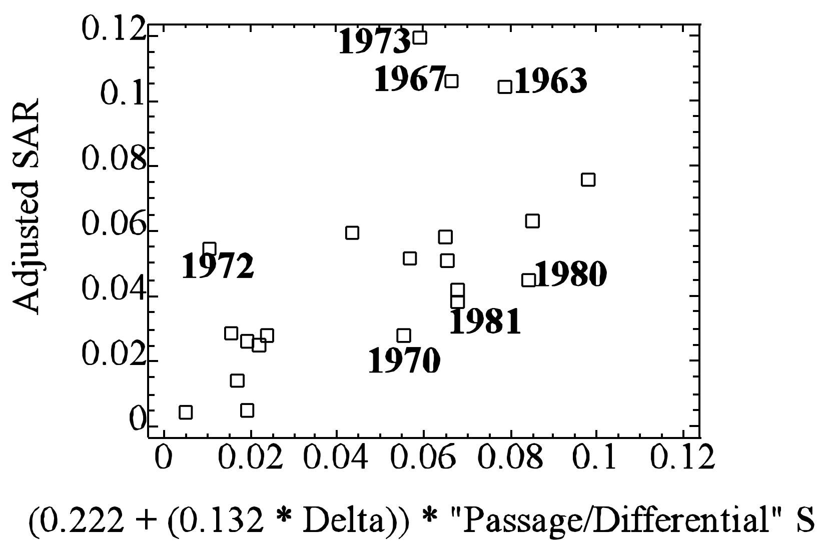

Figure 3. Adjusted SAR predicted from MLE parameters.

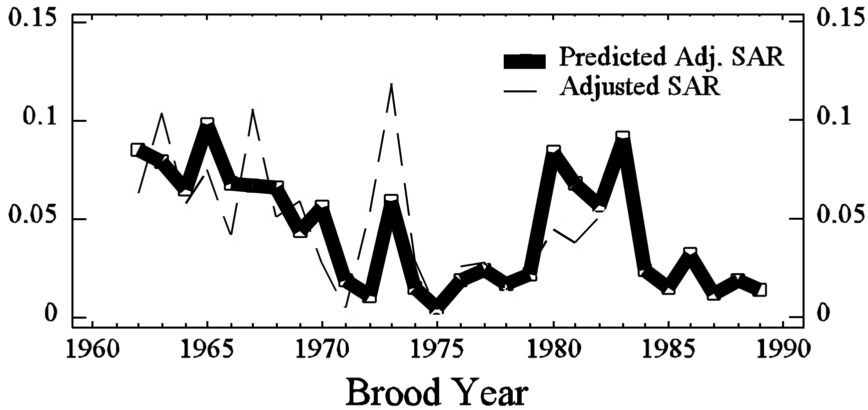

Figure 4. Predicted vs “observed” SAR by brood year.